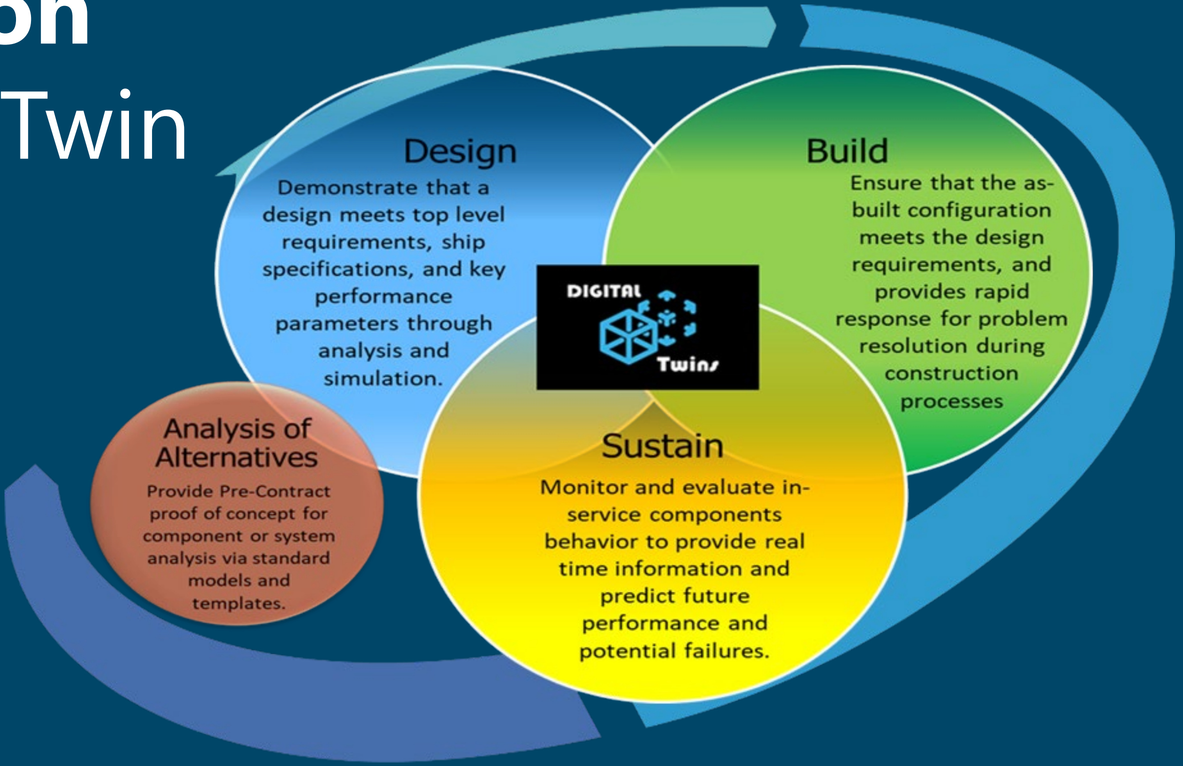
Digital Transformation
Digital Thread & Digital Twin Path Forward



NSRP All Panel Meeting

Charleston, SC

March 28-30, 2023

Presenter: Mark Debbink, HII-NNS

At HII, we view Digital Twins as tools with enabling capabilities that will move us forward with the introduction and integration of rapidly changing advanced digital technologies to our extremely complex ship designs.

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HII

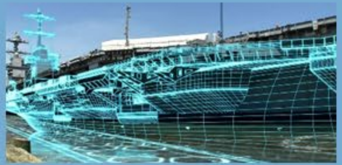
NEWPORT NEWS SHIPBUILDING

***Ford*-Class**
Aircraft Carrier Programs

Submarine Programs
New Construction

Aircraft Carrier Refuelings
(RCOH) & Inactivation

Submarine Onsite and
CVN Offsite Fleet Support Programs



Engineering and Planning Yard
Programs

Kenneth A. Kesselring
Site Operations

INGALLS SHIPBUILDING

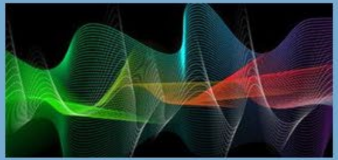
***America*-class**
Large Deck Amphibious Assault Ships

***San Antonio*-class**
Amphibious Transport Dock Ships

***Arleigh Burke*-class**
Aegis Guided Missile Destroyers

***Legend*-class**
National Security Cutters

MISSION TECHNOLOGIES



Cyber & Electronic Warfare

Live, Virtual, Constructive Solutions

Fleet Sustainment

Nuclear & Environmental Services

Intelligence, Surveillance & Reconnaissance

Unmanned Systems

Enabling the Navy the Nation Needs
Using Digital to Design, Build & Sustain our Navy's Fleet

WHY Go Digital?

Customer

- Tighter budgets
- Need for a bigger Navy (355 ships)
- Need accelerated acquisition
- Need more capable platforms
- Increased mission availability (A_o)

Workforce

- “The Great Workforce culture shift”
- Large workforce retirement
- Increased resource demand
- Decrease time to talent
- Greater competition for talent

Technology

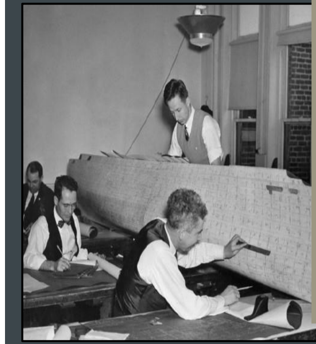
- Model Based Engineering
- Digital Twin
- AR/VR/MR
- Additive Manufacturing
- Artificial Intelligence

“We are not in a status quo time!” – Jennifer Boykin (NNS President)

Digital Twins are the Modern Design & CM Tools

Advanced technologies require an equivalently advanced architecture to operate & maintain design intent.

Blueprints to Paper Drawings

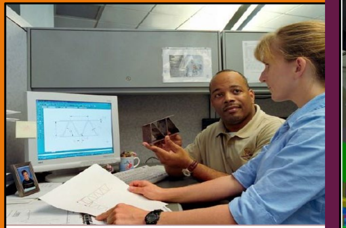


Origins-1960's

Migration to CAD

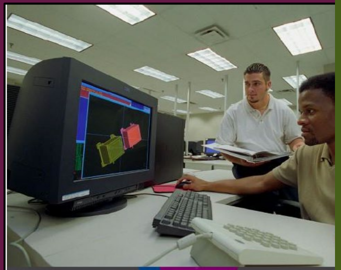
1960's-1970's

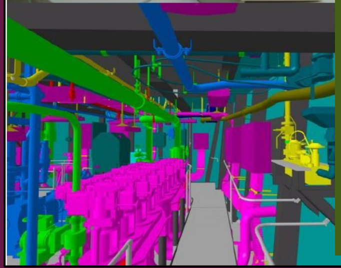
Migration to Solid Modeling



1980's-1990's

Migration to Product Modeling and VR





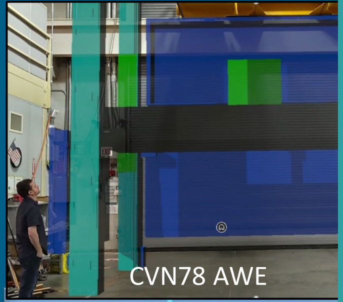
2000 - 2015

Development of Digital VWI's*

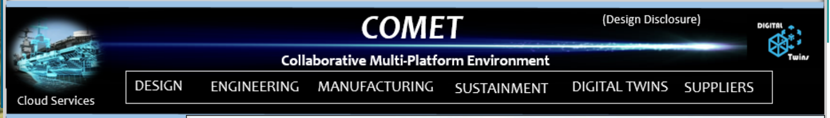
2015 – 2020's

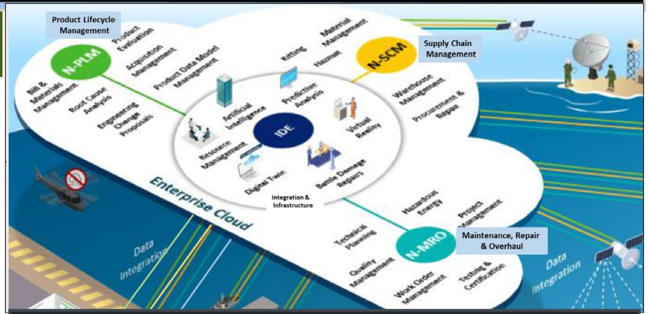
Current Paradigm

Development of Digital Twins



In-Service Sustainment; Exchange & Integration with Navy Systems





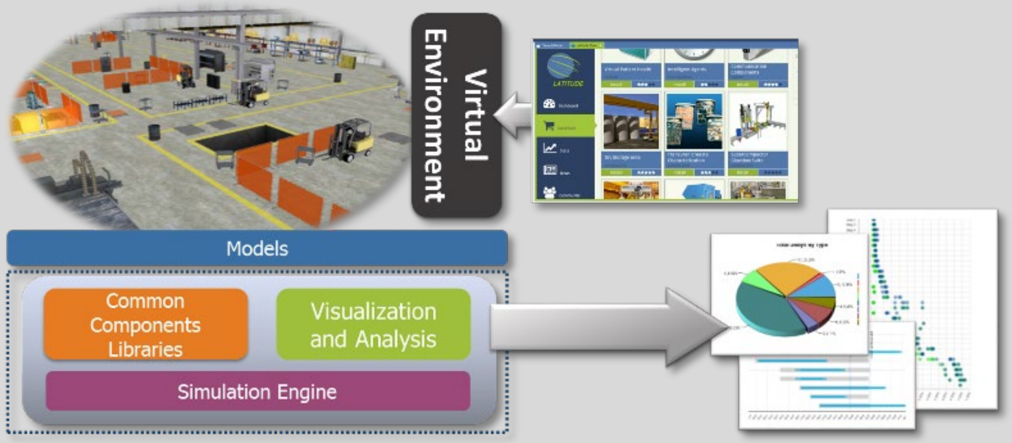
NPLM Cloud Env

* VWI: Visual Work Instruction

**Digital Twin technology has proven benefits today.
We need to determine where and how to best implement.**

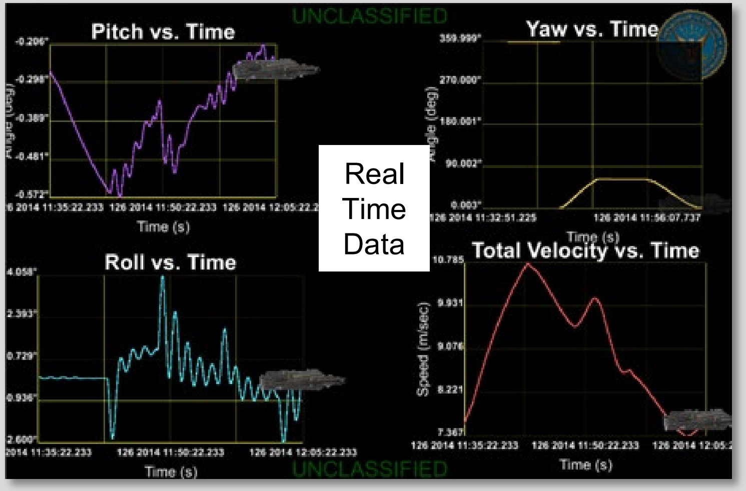
We are Building on Past NNS Modeling & Simulation Thrusts

Common Simulation Framework



CVN 78 Sortie Generation Model

Virtual Warship

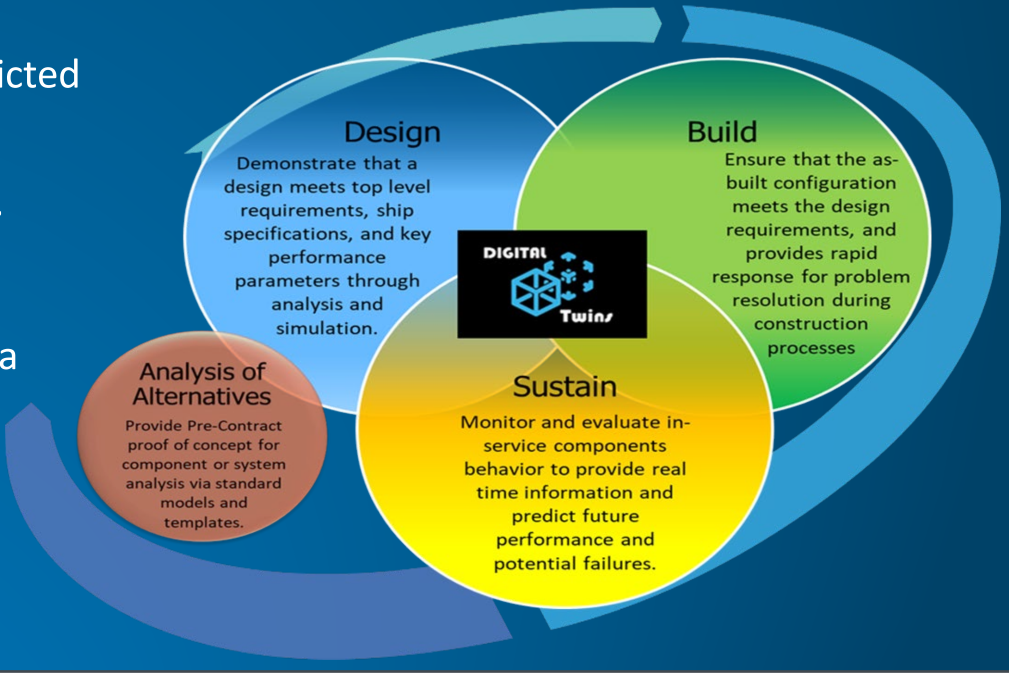


HII Digital Twin Definition: (Collaborative agreement between NNS, Ingalls, and MT)

*"A **digital twin** is a virtual representation of an asset (e.g. a component, a system, a ship, or a factory) or of a process (e.g. an assembly sequence). It can be used to analyze and specify requirements, understand the asset and optimize its behavior, interface with the asset and manage its configuration, and forecast* its future performance. The digital twin can exist in all phases of the digital thread – Design, Build, or Sustain.

A ***digital twin*** should include the following maturity characteristics:

- **Digital Models** of the asset, potentially including its geometry and predicted behavior (either simulated or derived from data).
- Association with a **Physical Asset** (component, system, ship, or factory).
- **Communications** via a bidirectional connection to that physical asset.
- **Knowledge** derived from comparisons of the models to operational data from the asset.



HII Digital Twin (DT) Infrastructure Framework

1 Digital Twin (DT) required?

Design

- Is a DT a Ship Spec requirement?
- Failure has a serious consequence?
- Does software control motion?
- Are there any significant hardware/software issues with the legacy or modified design?
- Does the component present significant cost, schedule, or development Risk?
- Will the prototype be used for software verification?
- Is the unit acquisition cost and/or quantity above a set threshold level?

Build

- Is the component required for System Integration Testing?
- Does prototype schedule support the integration testing schedule?
- Can a DT be used to demonstrate Top Level Requirements or Key Performance Parameter Requirements?
- Is this a major component / system in the build critical path?
- Does software control motion?

Sustain

- Does system have a high refresh rate?
- Are there known reliability problems with component, manufacturer / vendor?
- Would rapid remote support from Design Agent be required?
- Does it impact the overall availability of the ship?
- Will Sustainment lifecycle phase require component monitoring?
- Does the component have long lead time for replacement, limited or no spares? (managed obsolesces)
- Requires Analyze for End-Of-Life component performance?

DT Decision Tree

2 What type of DT is required?

Design

- Analysis of Alternatives (AoA) – Pre-Contract proof of concept for component or system
- Demonstrate that the design meets Top Level Requirements, Key Performance Parameters, and Ship Specifications.
- Ensure the design includes the necessary features (sensors, data collection, etc.) to support Digital Twin use in the Build & Sustain phases
- Provides Customer interface/ participation
- Demonstrate ability to test & verify future technology components
- May replace large scale land based mock-ups which have been traditional method of evaluation
- Reduce risk and support design development efforts

Build

- Provide feedback to validate the DT simulation models
- Prove reliability of design
- Optimize the construction schedule
- Minimize system integration and testing problems
- Ensure the as-built configuration meets the performance requirements (KPPs, TLRs, etc.) Prove reliability of design
- Problem resolution during construction processes

Sustain

- Monitor and evaluate in-service components behavior to provide real time information and predict future performance and potential failures.
- Optimize ship performance by varying component lineups based on operating conditions
- Optimize ship Availability (Ao)
- Enable rapid remote support from Design Agent
- Support Long lead time to replace this component; limited / no spares
- Manage obsolescence
- Enable Artificial Intelligence Steps
- Uncertainty of System conditions is minimized

DT Use-Cases & Benefits across the Digital Thread

3 DT Maturity Level needed?

HII - DIGITAL TWIN MATURITY MODEL

Maturity Level	Capability Description	Functional Description (Model Behavior, Capability Richness)	Characteristics
6	Autonomous Decision Making (Artificial Intelligence)	**3D Models**; (Autonomous Operations) by live synchronization and orchestration without any human intervention; Initiative operations supported with AI devices enabled with programmed parameters making decisions. **1D Models**; Autonomous Software Systems as stand alone products (Weapons defense system, data input & analysis to trigger action)	**(Intelligent)** Computer /Machine learning (ML) (happens by more than programmed responses) Human out of the loop (HOOL) Decisions by Computer Artificial Intelligence (AI)
5	Federated 2 way Exchange (Active Monitoring)	**3D Models**; (Active Monitoring), Federated, synchronized, and interactive operations among digital twins 2-way data integration with human intervention required for decision making. **1D Models**; Sensor data interpreted by human	**(Active)** External Data used in decisions Might be descriptive standards Could have programmed response Processed
4	Monitored / Sensors (Passive Monitoring)	**3D Models**; (Passive monitoring), Sensor Data, synchronized. Cause analysis possible by reproductive simulation with real-time data through twinning interface; connected devices to validate operational compliance with requirements are achieved. **1D Models**; Sensor data collected and compared to virtual model	**(Informative)** Internet of Things (IOT) Processing External Data Sensors Communication to Human (dashboard)
3	Modeling & Simulation (Systems / Physical / Integration)	**3D Models**; (Engineering) Virtual models interfacing with physical (hardware). Behaviors and dynamics modeled for operation and simulation validation. Perform what if situation analysis on a system level. May include HIL (Hardware in the loop), SIL (Software in the loop) and Smart diagram integration. **1D Models**; Analysis & integration for system models *Simulation: A representation of a system or design that contains all of the data possible and still allows real time operation.* *Model: A representation of a system or design that contains all of the data possible and still achieves mathematical convergence.*	**(Virtual Product Model)** Complex multi-system models Requirements Validation Hardware in the loop (HIL) System of systems Simulation (Speedgoat) Software in the loop (SIL) Network Integration Smart Diagrams
2	Virtual Modeling & Analysis (Discrete / Component)	**3D Models**; (Design) Mature 3D models supporting collaborative reviews, design / asset optimization, requirements validation, BOM, PMOM, MFG PMI, FEA component analysis and reporting on a component or system level, reality AR/VR MR rendering. **1D Models**; Functional Physics Based component models *Analysis: A process to study a proposed design's ability to meet requirements.*	**(Design Optimization)** Physics Based Analysis Behavior Driven Conceptual use-cases Events related
1	Virtual Models	**3D Models**; Model centric environment, physical objects are 3D modeled to have similar virtual appearance to a physical product, core attributes are attached to models. **1D Models**; Pre-Contract 1D models to support system evaluations and initial Analysis of Alternatives (AOA). These 1D models can exist before the 3D models are developed.	**(Arrangement Design)** Virtual - Computer Based Models Sketches 1D or 3D Models Diagrams Arrangements
0	2D Drawings	Drawing centric 2D design capture of product.	**2D Drawing Centric**
Maturity Level	Capability Description	Functional Description (Model Behavior, Capability Richness)	Characteristics

DT Maturity Levels

4 How Complex is the Model?

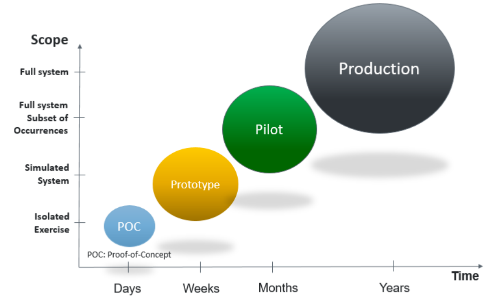
HII - DIGITAL TWIN FIDELITY MODEL

Capabilities/ Fidelity	Level 1 (Low)	Level 2 (Medium)	Level 3 (High)
1) Models & Data; Behavior/Availability	**Visualization Models** Models from standard (OOTB) application catalogs. Data available but not widely dispersed; features limited or ad hock.	**Simulation Models** Components have to be created in house or supplied by a vendor. Data is available and organized by product structure rules.	**Multiple Model Types** Supports AR/VR/MR, multiple CAD/CAE translations. Data organized and automated quality features run/evaluate continuously.
2) Analysis & Analytics Requirements	**Disconnected Systems** No customization; standard practices apply in calculations.	**Multi-Discipline Integration** Integration of traditional analysis tools / Simcenter analysis suite. Analysis models may be Linked to CAD models. Requirements Traceability links utilized.	**Optimization Analysis, Highly Specialized** Generative design (Set-Based) AI, ML capabilities Open collaboration with others enabled.
3) Configuration Management	**Manual** CM through product line servers & other disconnected repositories.	**Procedural & Technology Interface** Limited automation CM through Integrated PDM system.	**Automated Management** Continuous running. System of Systems, a large network of components, sophisticated information processing.
4) Model Validation	**Manual Checks and Balances** Model performance metrics defined, limited validation.	**Limited Automation for Checks & Balances** Rule based checks run manually (Checkmate) Dedicated high performance machines with potential to improve on cluster.	**Compute On-Demand & Optimized** Compute On-Demand & Optimized, rules defined and processed behind scene Always available, User display of status.
5) System Integration & Interfaces	**No Software Integration** Manual push/pull of data across systems.	**Some Software Integration & Automated Data Transfer** Scheduled events run to integrate data across systems.	**Fully Automated Comprehensive Checks & Balances** Many-to-many communication channels with embedded software systems. Smart User Interface (UI)
6) Intelligence	**Descriptive** (Data-Information) Limited to visualization with linked metadata access.	**Prescriptive** (Information-Knowledge) Behaviors and dynamics modeled for operation and simulation validation. Human intervention required for decisions.	**Predictive & Autonomy** (Knowledge-Wisdom) Federated, synchronized, and interactive operations with Digital Twin 2-way data integration. No human intervention for decisions.
7) Standardization	**No Standardization** Independent work	**Partial Standardization** Documented work methods Some procedures in place	**Comprehensive Standardization** All Processes & Training in place Solution Validation & Verification processes in place

DT Complexity / Fidelity Levels

5 Environment Phase Needs?

(Digital Twin development stages will define the necessary Maturity & Capability Levels)



DT Needs change with development phases

This framework will provide a strategy for Digital Twin evaluation, development, and planning.

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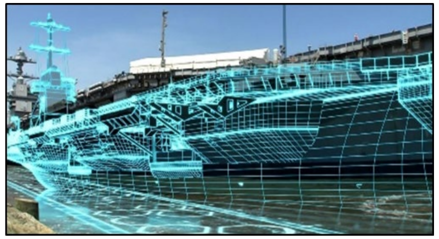
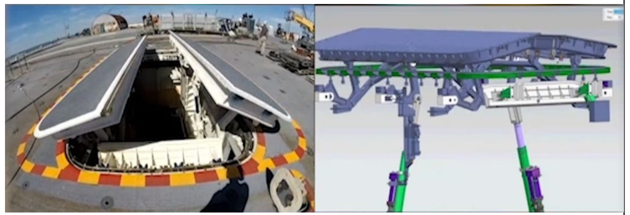
Note: The Capability Model is intended to be used in conjunction with the Digital Twin Maturity Model to fully describe a Digital Twin.

Digital Twins at NNS

(Comparison of Maturity & Complexity Levels)



Aircraft Carrier Elevators
(Design Validation & Problem Resolution)



(DT's of Operationally Complex components/systems)

Tools to Accomplished the DT

Functional/Physics Based w/Product Model Geometry
- MATLAB
- SIEMENS Simcenter
- Modelica Association

Hardware in the Loop/AR
- MATLAB
- speedgoat real-time simulation and testing
- DOGFISH LABS

No single provider has a complete DT tool set.

5	Federated 2 way Exchange (Active Monitoring)	**3D Models**; (Active Monitoring), Federated, synchronized, and interactive operations among digital twins 2-way data integration with human intervention required for decision making. **1D Models**; Sensor data interpreted by human	(Active) External Data used in decisions Might have descriptive standards Could have programmed response Processed

Maturity Level - 5
Complexity Level – 2

Multi-Physics Transient Models
- MiL (Model in the loop)
- SiL (Software in the loop)
- HiL (Hardware in the loop)

Aircraft Carrier Logistics Components & Metadata
(On-Board Ship access to Digital Twins)

OEM Input

Original Data From OEM
- **3D Product Models**
  with Design Data
  with Location Data
  with Label Plate Inscriptions
  with Gov Data References*
- **Logistics Support Parts**
  with Gov Data References*

Simulated Data From OEM
- **TWR Ship 3D Prd Models**
  with Gov Data References*
- **Logistics Support Parts**
  with Gov Data References*

Navy Input

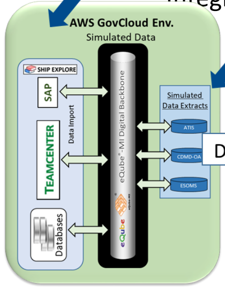
Simulated Data From Gov
- **CDMD-OA**
- **Tech Manuals**
- **Drawings**

Original Data From Gov
Tech Data such as:
- CDMD-OA
- ESOMS
- etc.

Documents such as:
- Tech Manuals
- ATIS/Drawings
- etc.

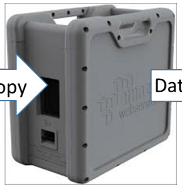
Multi-System Integration

On-Board Ship 3D Environment Project



Cloud Env.

Data Copy



Snowball DB

Data Access

Shipboard Access

Providing Increased time & efficiency at Sea.

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Maturity Level – (1-2)
Complexity Level – (2-3)

Multi-System Integration
- ~4 Million parts
- ~3 Billion Attributes
- > 10K Doc's